Quantifying The Health Factor as a Mediator of the Pollution-Productivity Relationships in Indonesia

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Abstract

Pollution (in this term, air pollution) is an environmental phenomenon that negatively impacts the lives of the broader community and harms all aspects of the human dimension, such as health and the economy. This study aims to quantify the impact of pollution on worker productivity in developing countries using longitudinal data from Indonesia in two periods (2007 and 2014) and utilizing satellite data to represent air pollution data better. This study uses an instrumental variable (IV) approach and expands it by quantifying health aspects as one of the transmissions in the relationship between pollution and productivity. The result is that pollution negatively impacts worker productivity, with a dominant negative effect transmitted by health factors and determines their productivity. For this reason, the government is involved in tackling increasing pollution to minimize the increase in disease cases while minimizing economic losses from this phenomenon in the future.

Keywords: Pollution; Labor Productivity; Instrumental Variable (IV); Mediation Analysis; Developing Country

JEL Classification: J21, J22, J24, Q52, Q53

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I. Introduction

1.1 Background

Comprehending the distinctive attributes of labor supply and making substantial investments in human capital represent pivotal endeavors for fostering sustained economic growth and amplifying productivity (Joshua et al., 2012; Rolph, 2016). The labor market, with its ensuing outcomes, occupies a central role across diverse economic spheres, exerting a profound impact on stability, progress, and overall well-being (Heintz, 2009; Terziev, 2019). The issue of employment quality assumes paramount significance in Indonesia, where the pace of labor productivity gains has been notably lethargic. To facilitate the proliferation of higher value-added activities, a comprehensive strategy aimed at expediting labor productivity becomes imperative (Allen, 2016). In the intricate landscape of labor-related challenges in Indonesia, a particularly overlooked facet pertains to workplace pollution (Neidell, 2017). Concurrently, pollution emerges as a formidable hindrance to progress. Notably, ambient air pollution alone is estimated to have caused approximately 4.2 million premature deaths globally in 2019. A staggering 89% of these fatalities occurred in low- and middle-income countries, predominantly concentrated in the WHO Southeast Asia and Western Pacific Regions (WHO, 2022). Amid the multifaceted repercussions of pollution, a dimension that warrants increased scrutiny is its impact on health. Chronic respiratory conditions, especially prevalent in older individuals exposed to risk factors such as indoor air pollution, significantly contribute to the overall burden of health (James et al., 2018). This nuanced exploration underscores the intricate interplay between labor dynamics, productivity, and the pervasive challenges posed by workplace pollution, urging a comprehensive examination for informed policy interventions and sustainable economic advancement.

The environmental challenge in Indonesia mirrors a global concern, particularly regarding PM2.5 pollution, which poses a significant threat to public health. Studies indicate that this form of pollution can lead to a reduction in the average resident's life expectancy by 1.4 years when compared to adherence to World Health Organization (WHO) guidelines (AQLI, 2023). In specific regions like Deli Serdang, the consequences are even more severe, with air pollution diminishing life expectancy by 2.9 years. PM2.5, recognized as a pivotal indicator of outdoor air quality and aligned with WHO guidelines for air pollution (Health Effects Institute, 2019; Kim, Manley, and Vlad Radoias, 2017), amplifies the urgency of addressing this environmental dilemma. Adding to the complexity, a recent report by the World Bank underscores the substantial economic toll of air pollution on Indonesia, amounting to over USD 220 billion annually or 6.6% of the country's GDP PPP in 2019 (World Bank, 2022). From an empirical research perspective, existing literature highlights the detrimental impact of pollution on productivity, primarily mediated through health considerations (Li et al., 2020; Neidell & Pestel, 2023). Despite the plethora of global evidence shedding light on the adverse health effects of air pollution, there exists a notable dearth of localized evidence addressing the specific burden of air pollution, particularly its impact on labor productivity, in the context of Indonesia.

Air pollution primarily impacts mechanisms through three key avenues. **Firstly**, the detrimental effects on health, particularly respiratory issues, have been extensively studied, with a focus on the physical and mental well-being of individuals. However, limited attention has been given to the crucial link between changing air quality and productivity. Existing research emphasizes that workers facing health problems struggle to perform efficiently, while improved health and a better workplace environment can enhance productivity (Dong and Wang, 2023; Mohsen Asadi Lari, 2024). This underscores a direct correlation between air pollution, declining individual health, and subsequent reductions in labor productivity.

Secondly, the presence of ailing family members poses trade-offs for workers between labor supply times and caregiving responsibilities. The deteriorating health of workers' families contributes to increased labor costs and shortened labor supply times (Urwin et al., 2023; Keita et al., 2023; Stanford and Jacobs, 2023). Empirical evidence highlights the negative impact of caregiving on productivity, emphasizing the trade-offs and opportunity costs involved (King et al., 2020; Duc Dung Le and Ibuka, 2023). However, insufficient attention has been directed towards understanding the specific impact of pollution on productivity within this context. **Thirdly**, heightened pollution levels can decrease utility in consumption, subsequently diminishing the value of productivity among workers. Changes in an individual's marginal consumption utility have the potential to harm productivity or labor supply (Gu, Bian, and Elahi, 2020; Chang et al., 2019). This aspect highlights the need for a more nuanced exploration of the process through which pollution affects productivity, shedding light on the intricate dynamics between pollution, individual well-being, and labor supply.

This research seeks to bridge this critical knowledge gap by offering comprehensive insights into the intricate dynamics interlinking pollution, health outcomes, and labor in the Indonesian setting. The study addresses the theoretical ambiguities surrounding the impact of pollution on work hours, challenging conventional beliefs. For completing the objectives, we use several methodology, including ordinary least square (OLS), panel fixed-effect (FE), instrumental variable (IV), and IV mediate approach. All methodologies are used for capturing the pollution-productivy relationship and calculating the health factor as main transmition for the relations. This study posits that an improvement in environmental quality may actually enhance productivity by fostering a healthier workforce, thereby challenging the prevailing notion that environmental regulations impede economic progress. Through rigorous empirical analysis, this research aspires to contribute substantively to both the scholarly discourse and policymaking efforts aimed at mitigating the multifaceted challenges posed by air pollution in Indonesia.

1.2 Research Purpose

This study aims to assess the direct influence of air pollution on economic activity, particularly within the labor context, emphasizing the unique contribution to existing literature. The impact of air pollution on labor activity has far-reaching consequences for the economic value of work, extending beyond direct health-related costs. Social costs associated with pollution (Kim, Manley, and Vlad Radoias 2017)., even in cases of mild health issues, encompass both direct financial burdens on affected individuals and additional societal costs due to reduced labor force participation or productivity. Existing literature extensively documents the detrimental effects of pollution on labor supply (Aragon, Miranda, and Oliva 2016; Hanna and Oliva 2015;

Wu, Yan, and Elahi 2022), exploring various factors such as caregiving (Kim, Manley, and Vlad Radoias, 2017; Holub, Hospido, and Wagner, 2020) and income level (Zhang Zongyong et al. 2018). While previous research has considered the prolonged negative impact of pollution on labor through its influence on individual health (Kim, Manley, and Vlad Radoias 2017), there is a notable gap in the literature regarding Southeast Asian countries, particularly Indonesia. Despite some studies addressing variables influencing work behaviors and pollution (Joshua Graff Zivin and Neidell 2012; Chang et al. 2016; Neidell 2017; Dong and Wang 2023, uncontrolled and unobservable factors may still impact estimated relationships. This research seeks to fill this void by investigating the impact of air pollution on overall labor productivity that providing valuable insights into the specific context of Southeast Asia, especially Indonesia.

In our pursuit of novelty, we venture beyond the conventional approach of assessing the negative impact of air pollution on economic activity solely through health mediation. Extensive exploration of the health effects of air pollution, particularly the concentration of Particulate Matter (PM), has been documented in medical literature. Numerous prior studies have causally linked air pollution to public health, addressing its impact on a variety of health outcomes (Jos Lelieveld et al., 2015; Chen et al., 2007; C. Arden Pope et al., 2009; Ritz, 2010; Landrigan, 2017; Calderón-Garcidueñas et al., 2014; Qin et al., 2023). Focusing on fine particulate matter, pollution affects respiratory issues (Brunekreef and Holgate 2002; Adam et al. 2014; Stewart et al. 2015; Adamkiewicz, Liddie, and Gaffin 2020; Sarno et al. 2023; Wu et al. 2022), mortality (Chen et al. 2007), and leukemia (Magnani et al. 2016). Furthermore, improved air quality has been correlated with enhanced cognitive function and mental health. Given the extensive body of evidence linking pollution to adverse health consequences, our novel approach suggests that efforts to reduce pollution can be viewed as an investment in human capital, potentially fostering economic growth rather than hindering it.

II. Data and Methodology

2.1 Data

This research utilizes panel microdata that can capture Indonesia's national context. Thus, we use the Indonesian Family Life Survey (IFLS) from the RAND Organization. IFLS is an ongoing longitudinal survey in Indonesia that represents about 83% of the Indonesian population and contains over 30,000 individuals living in 13 of the 27 provinces in the country. This publicly accessed data contains five waves of data, that is the first wave of the IFLS (IFLS1) was conducted in 1993/94 by RAND, and the last wave, the fifth wave of the IFLS (IFLS-5), was fielded in 2014-2015 (RAND Organization, 2024). Thus, this study uses only two waves of IFLS: IFLS4 in 2007 and IFLS5 in 2014. However, we restrict the observation to only the respondents considered to be working age (>= 15 years) but less than 100 years old and in the household for two data editions, which gives us the strongly-balanced longitudinal data. Those data sets contain many individual and household characteristics for capturing the pollution-productivity relationship.

There is no specific measure of labor productivity. It can be as unique as the work sector that Kögel (2023) summarizes and uses by Ma et al. (2020). Labor productivity is represented as the amount of labor time lost related to morbidity (Wang et al., 2020), Gross Value Added over total employment at current prices at firm levels of the Kögel (2023) approach, and GDP per worker (Ren et al., 2022) for more macro context. Besides that, other literature uses work hours to measure labor productivity (Zhao et al., 2024). Referring to the related literature, we use general labor productivity of hours worked last week to capture the individual work hours within a week on the interview date, and we transform it into a natural logarithm form.

Further, we use $PM_{2.5}$ concentration to represent the level of air pollution since $PM_{2.5}$ is one pollutant in air regulated in the form of ambient air quality standards (Nazarenko et al., 2021). As a pollutant, a high level of $PM_{2.5}$ concentration can lead to several effects, primarily on health and mortality (Zheng et al., 2015). This proxy is also used in the range of fields of work related to environmental impacts (Kögel, 2023; Ren et al., 2022). Other pollutants that can be used as proxies for air pollution are PM_{10} and NO_2, like Breivik, Holmås, & Riise's (2020) approach. However, the availability of air pollution data from government or official organizations is limited to the provincial and national levels, thus leading to the variability of data when we merge with individual-level data. Thus, we expect to get the narrower level of pollution data: city/regency level.

To accomplish that, we extract the grid-based data from satellite MERRA-2 (Modern-Era Retrospective Analysis for Research and Applications version 2) produced by NASA Global Modeling and Assimilation Office (GMAO) using the Goddard Earth Observing System Model (GEOS) version 5.12.4. MERRA-2 is global spatial grid data with spatial restriction of 0.5° x 0.625° from 1980 until now (GMAO, 2023). Then, we use air pollution proxy from the Aerosol Diagnostics section and Dust Surface Mass Concentration – PM2.5 that is captured with frequency of 1-hourly from 00:30 UTC. Then, we standardize the measurement into the standard official measurements of $\mu g m^{-3}$. For simplicity, we use monthly time-averaged and the R packages of exact extracts that facilitate the extraction in a raster referring to polygonal features. We use the function of weighted mean that calculates the mean cell value by weighting the product of the fraction of each cell covered by the polygon. Then, the air pollution data is matched toward individual data of IFLS using their city/regency code and month and year of the individual being interviewed for ideal representing condition for all respondents and transform it into natural logarithm form. Also, we have instrument variable of air temperature and meteorological vector (wind speed and air density) that using the same approach of air pollution.

Furthermore, we use three types of control, including individual controls (e.g., education, working status, sector, health insurance, smoking behavior, age, square of age, marital status, urban, gender), household (ownership of house and vehicle), and regional controls (Nominal GDRP, inflation, population density, and Human Development Index). We get individual and household control from IFLS, but regional controls are from the Statistical Agency of Indonesia (Badan Pusat Statistik). **Tabel 1** represents the summary statistics and **Appendix I** captures the list of detail operationalization variables**.**

	Mean	**Median**	**Min**	**Max**	**Stev**
Productivity	36.15	1500	1000	2000	20,80
		Individual Control Variables			
Health Insurance	*0.337*	*0.337*	*0*	*1*	*0.473*
Sector	*1.910*	*1.910*	*0*	*98*	*8.484*
Smoking	*1.050*	*1.050*	*0*	*3*	*1.401*
Education	*13.65*	*13.65*	*0*	*98*	*31.42*
Age	*42.27*	*42.27*	*15*	*100*	*15.21*
Square of Age	*2,453*	*2,453*	*225*	*996,004*	*20,807*

Marital Status	*0.998*	*0.998*	*0*	*98*	*1.123*
Urban	*0.555*	*0.555*	*0*	*1*	*0.497*
Gender	*0.465*	*0.465*	*0*	*1*	*0.499*
	Household Control Variables				
House Ownership	*5.872*	*5.872*	*0*	*98*	*17.58*
Vehicle Ownership	*0.668*	*0.668*	*0*	*1*	*0.471*
	Regional Control Variables				
Population Density	*6.336*	*6.336*	*2.565*	*9.637*	*1.263*
Nominal GDRP	*12.64*	*12.64*	*8.731*	*14.50*	*1.203*
Inflation	*5.066*	*5.066*	*4.712*	*5.720*	*0.250*
Human Development Index	*4.255*	*4.255*	*4.131*	*4.369*	*0.0445*
	Instrument Variable				
Air Temperature	*5.631*	*5.631*	*5.585*	*5.680*	*0.0175*
	Meteorological Vectors				
Wind Speed	*2.046*	*2.046*	*1.171*	*2.635*	*0.286*
Air Density	*0.223*	*0.223*	*0.0720*	*0.252*	*0.0225*
	Mediator Variable				
Health	*0.386*	*0.386*	*0*	*1*	*0.487*

Table 1. Descriptive Statistics

Source: RAND Organization (2007 & 2014). GMAO (2023), & BPS (2023), Author's Calculations

2.2 Methodology

This study using several estimation approach, such as ordinary least square (OLS), panel fixed-effect. First, we use the OLS method to see the negative relationship between air pollution levels and health levels.

$$\boldsymbol{Productivity_{it} = \beta_0 + \beta_1 Pollution_{jt} + \beta_2 X_{jt} + \beta_3 R_{kt} + \epsilon_{it}} \quad (1)$$

with productivity is the average working hours during the week of the main job carried out by a sample of individuals *i* at time *t*. The pollution level shows the $PM_{2.5}$ value which is logarithmic at city/regency level *j* and a certain time *t*. Then the we add several control variables, including individual characteristics and household characteristics. To capture the economics activity as whole, we use province level data of province *k* at time *t* characteristics.

For implement the methodology, there are challenges in pollution on labor supply and productivity related to endogeneity. **First**, reverse causality occurs because as firms increase their production by adding more labor supply or productivity, they emit more pollution (Neidell 2017; Li and Li 2022; Chang et al. 2016; Wu, Yan, and Elahi 2022) and potentials of bi-directional relationships (Kögel, 2023). Therefore, higher levels of labor supply or productivity lead to an increase in pollution. **Second**, selection bias because certain factors inherently determine an individual's exposure to air pollution. Individuals may choose to reside in better environments, access, or neighborhoods influenced partly by their income level (Jang and Yi 2021), which is determined by their level of productivity (Banzhaf and Walsh 2008). **Third**, measurement errors arise when using data from developing countries because of sparse pollution data (Olimpia, Hanna, and Oliva 2012). Moreover, although it is common for datasets to assess output per worker, these assessments fail to distinguish worker productivity from other factors such as capital and technology (Joshua Graff Zivin and Neidell 2012).

In addition, difficulties in gathering productivity data make it poorly measured (Djellal and Gallouj 2013). Consequently, acquiring accurate measurements of worker productivity remains an ongoing difficulty. To handle endogeneity in pollution, a large body of literature uses the instrumental variable method (Olimpia, Hanna, and Oliva 2012; He, Liu, and Salvo 2019; Li, Shi, and Zeng 2020; Olivier Deschênes et al. 2020; Li and Li 2022).

Thus, we use Instrumental Variable (IV) for overcoming thoses issues of estimation. We use air temperature for the instrument variable due to their effect on air pollution. But, for controlling the weather conditions, we use meteorological control, such as wind speed and humidity that extracted also from MERRA-2 satelitte. Later, this study examine this pollution-productivity relationships using instrumental variable approach, since the air pollution is endogenuous independent variabel due to human activity. With this regard, we use the air temperature as instrumental variable. Although there are several studies believe that air temperature is determined by the human activity (**see** Lai & Cheng, 2010), this study believe in short period of time, air temperature is exogenuous (Schultz & Mankin, 2019). But, we realize that air temperature hugely related to geographic conditions of area (**see** Arceo, Hanna, and Oliva 2016) and need to control meterological vector that also determined the air temperature like used in Chan & Zhang (2021) and Kögel (2023) approach. At this study, we use two different meteorological vectors, namely air density and windspeed at city/regency level.

After that, this study attempts to see the impact of air pollution on productivity using mediation analysis. Mediator we use the health status of individual from IFLS. Clearly thoughts that pollution affect the labor productivity via total hours worked and increase abstenteeism, thus linked the health factor transmission (Kögel, 2023). However, Kim et al. (2017) noted other mediator of pollution towards the labor productivity, and found that the mediator is changed over time. In medium-term, the negative impact of air pollution is transmitted primarily of caregiving aspects of labor. However in the long-term, individual health status transmitted the negative impact. For now, we only use health as mediator. In its analysis, mediation analysis aims to provide a causal picture of how the mechanism of a policy or event can influence an inevitable outcome through a mediator who is in the middle of the pathway between treatment and outcome (Imai et al., 2013). In economics, mediation analysis can answer what Celli (2022) calls the *black box* of treatment mechanisms in influencing outcomes. Several studies in the economic or social realm use mediation analysis, such as Mendolia and Siminski (2017), Daniel, Pande, and Rietveld (2020), and Nasrudin, Quarina, and Dartanto (2022). However, this study applies the mediation analysis approach that Nasrudin, Quarina, and Dartanto (2022) used using the STATA syntax developed by Dippel, Ferrara, and Heblich (2020) called *ivmediate*.

Regarding our concern, that STATA syntax can decompose the effect of air pollution on labor productivity into two effects, direct and indirect, by using single instrumental variable estimation. **Further**, we utilized two parts of estimation—the first part focuses on estimating the effect of air pollution on health factors as a mediating variable. After the first part, we estimate the effect of air pollution on health as a mediator and the direct effect on labor productivity using the two least squares (TSLS) stages. The two are represented in the equation below:

First Part

First Stage:

$$Pollution_{jt} = \beta_0 + \beta_1 Temperature_{jt} + \tau \boldsymbol{X_{it}} + \omega \boldsymbol{R_{kt}} + \boldsymbol{\sigma Meteorogical_{jt}} + \epsilon_{it} \quad (2)$$

Second Stage:

$$Health_{it} = \delta_0 + \delta_1 \widehat{Pollution}_t + \boldsymbol{\delta X_{it}} + \boldsymbol{\rho R_t} + \boldsymbol{\psi Meteorogical_{jt}} + \alpha_{it} \quad (3)$$

Second Part

First Stage:

$$Health_{it} = \theta_0 + \theta_1 Pollution_{jt} + \theta_2 Temperature_{jt} + \theta \boldsymbol{X_{it}} + \pi \boldsymbol{R_{kt}} + \boldsymbol{\varrho Meteorogical_{jt}} + \zeta_{it} \quad (4)$$

Second stage:

$$Productivity_{it} = \lambda_0 + \lambda_1 \widehat{Health}_{it} + \lambda_2 Pollution_{jt} + \lambda \boldsymbol{X_{it}} + \varphi \boldsymbol{R_{kt}} + \boldsymbol{\tau Meteorogical_{jt}} + \phi_{it} \quad (5)$$

This methodology decomposes the effect of air pollution on labor productivity into two effects: direct effect and indirect effect. The magnitude of λ_2 represents the direct effect of air pollution on labor productivity, and the magnitude of $\lambda_1 \times \delta_1$ represents the Indirect effect. Total effect is the sum of direct effect and indirect effect. With this estimation, we can see the health effect as an indirect effect of air pollution that determines labor productivity in Indonesia. Before that, we also calculate the baseline estimation discussed in the following section.

III. Results and Discussion

In Indonesia in The level of labor productivity in Indonesia has changed over time. It varies with the characteristics possessed by individuals, which are then depicted in **Figures 1a** to **Figure 1d**. It can be seen in Figure 1a that the level of labor productivity in urban areas is higher than in rural areas in the two editions of the IFLS. On a median, people in urban areas worked around 40-42 hours a week in 2007 and 2014. In the same period, people in rural areas worked approximately 30-35 hours a week. However, if we look closely, the level of labor productivity in these two areas has decreased. In urban areas, labor hours worked in 2014 decreased by 4.8% compared to 2007, while individual work hours in rural areas fell more sharply, by 14.3%. Then, concerning gender, it can be seen that men's productivity levels are more significant in the two editions of the IFLS (42 hours in 2007 and 40 hours in 2014).

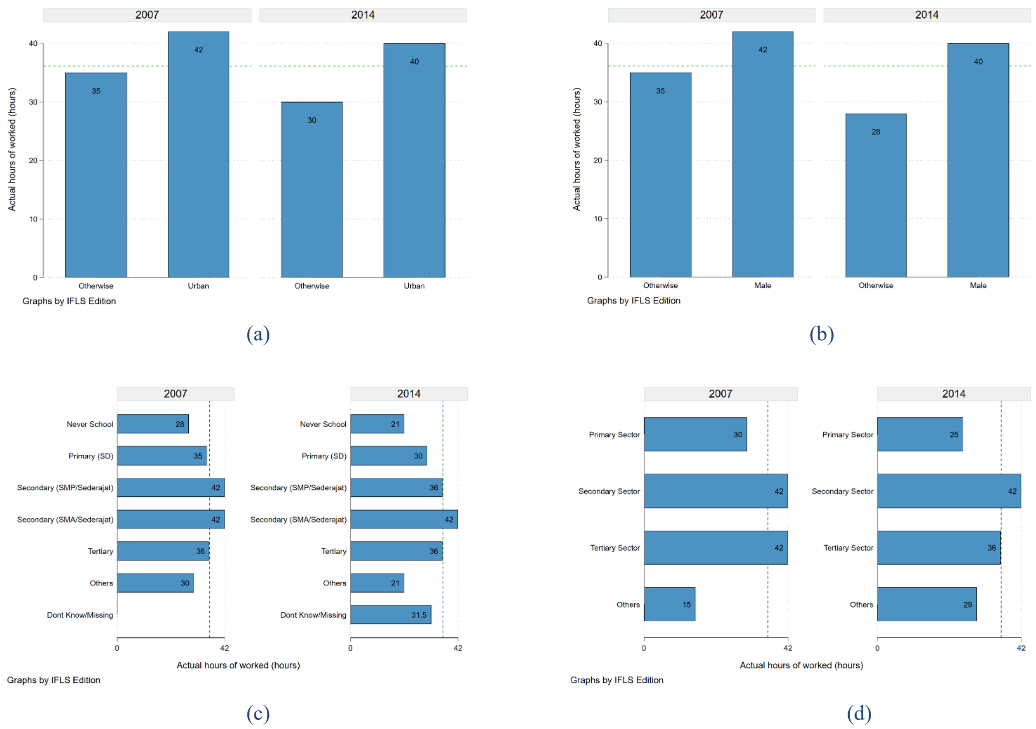


Figure 1. Labor Productivity in Indonesia by several characteristics: (a) urban/rural area, (b) gender, (c) education level, and (d) working sector[1]

Source: RAND Organization (2007 & 2014), Author's Calculations

Based on educational characteristics, individuals with a secondary level of education had a higher level of working hours in these two periods than those with the same level of education. This aligns with the median working hours in the secondary sector, 42 hours a week in the two observation periods. On the other hand, individuals with tertiary education characteristics have constant working hours in the two periods (i.e., 36 hours a week). However, the tertiary sector experienced a decrease in working hours in 2014 by 14.3% compared to 2007. Finally, individuals who did not attend school or received primary education had the lowest working hours, in line with the primary sector, which had the lowest median working hours (i.e., 30 hours in 2007 and 25 hours in 2014).

[1] The working hours in several characteristics use the median level of individual hours worked last week to avoid the extreme value impact on data distribution. The green dashed line represents the mean of labor hours worked at two years of the IFLS edition.

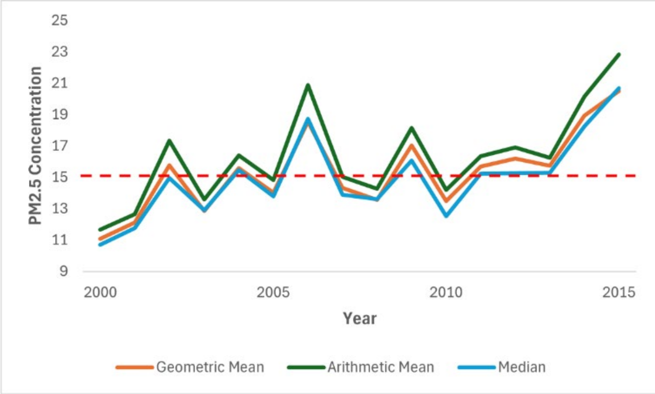
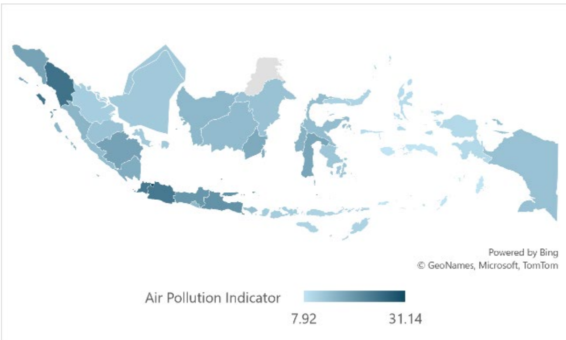


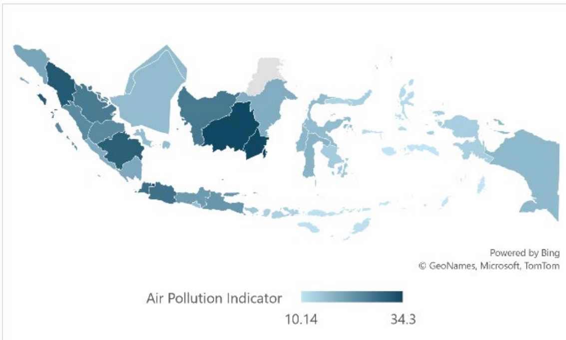
Figure 2. The Air Pollution in Indonesia Since 2000[2]

Source: EPIC (2023), Author's Calculations

Regarding air pollution trends in Indonesia, **Figure 2** shows the movement of average air pollution levels in Indonesia after the 2000s. Pollution trends in Indonesia tend to fluctuate from year to year in terms of average and median pollution levels. However, after 2010, the trend in air pollution was consistently in a positive direction until 2015. Based on its distribution in the provinces (see **Figures 3a** and **Figures 3b**), the areas with the highest levels of air pollution were in provinces on the island of Java, along with North Sumatra Province in 2007. However, in 2014, the levels of Air pollution increased in several provinces, such as Riau, South Sumatra, Central Kalimantan, and South Kalimantan. Several causes include increased community activities (i.e., using vehicles) (Ministry of the Environment, 2011). Natural disaster factors also play a role in increasing levels of air pollution in Indonesia, especially in 2013 and 2015 in the Sumatra region (Sizer et al. 2014) and the Kalimantan region (Arifa 2022). In Jakarta, the nation's capital, pollution levels were consistently high in the two periods. Transportation, industrial activities, and power plants are said to be sources of air pollution (Vital Strategies, n.d.).



(a)



(b)

Figure 3. Air Pollution Distrbution Across Province: (a) in 2007 and (b) in 2014

Source: GMAO (2023), Author's Calculations

Concerning the level of labor productivity, we are interested in seeing the relationship through a graphic depiction using a scatter plot. By utilizing city/regency observation level, as presented by **Figure 4**, we can see a negative relationship between air pollution levels and labor productivity. Then, when viewed using a linear fitted plot, there is indeed a negative relationship between the two variables even though the slope is

[2] This use the unweighted concentration of PM2.5 in all provinces in Indonesia over the period of time. We use several mean measurements and compare it to the median value for giving the better comparison.

slight, indicating that the relationship between the two variables is not too big. For this reason, we need to look at the relationship between the two variables using inferential estimation, as explained in the following sections. Exposure concentration of PM2.5 reducing labor working time and increase premature death by causing excessive morbidity and mortality (Wang et al., 2020). But, sectoral plays dominant effect of negative impact from air pollution, since energy-related industries, with mostly male and low-educated face greater health effects (Wang et al., 2020).

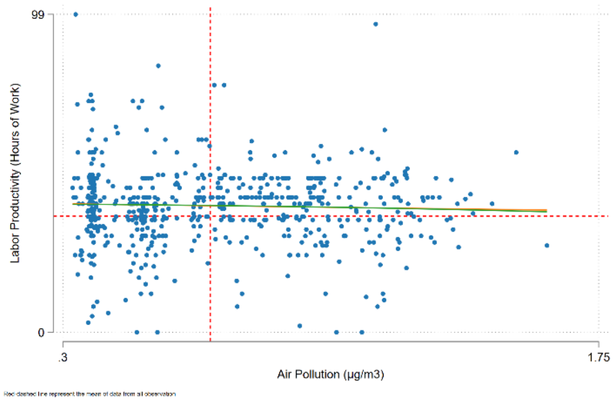


Figure 4. Pollution-Productivity Relations: Scatterplot Analysis[3]

Source: GMAO (2023), Author's Calculations

Further, we move toward the estimation of the inferential statistics. We use several estimation methodologies, such as OLS, fixed-effects, and instrumental variables, to see this negative impact in Indonesia. The baseline estimation results can be seen in **Table 2**. In line with He, Liu, and Salvo (2019), the study causes an increase in the cost of effort of labor when working, which then affects the level of labor supply. However, this study makes health the primary transmission of air pollution. The level of air pollution then has a negative influence on the health of workers. It has the potential to cause respiratory diseases (such as lung cancer and pneumonia) and other chronic diseases (stroke, ischemic heart disease, chronic obstructive pulmonary disease) (WHO, n.d.), which then creates a decline in labor productivity.

Using OLS (Columns 1-3), it can be seen that the pollution level has a positive relationship with the level of labor productivity, both without and using control variables (individual and regional). It can be seen that a 1% increase in air pollution levels can increase labor productivity levels between 0.02%-0.07%. These results are also estimated using fixed-effects (Columns 4-6) (except full-model) with similar magnitudes. This result differs from findings (i.e., He, Liu, and Salvo 2019; Hanna and Oliva 2015; Chen and Zhang 2021) that show a negative relationship between air pollution levels and labor productivity. Given that OLS and fixed effects have weaknesses in estimation, we decided to estimate using the instrumental variable methodology (Columns 7-9). The air temperature level is an instrument variable. Besides using individual and regional characteristics, IV estimation also adds vectors to control for the meteorological characteristics of each region. The results found that the level of air pollution harms the level of labor productivity in Indonesia. A 1% increase in air pollution can reduce labor productivity by 0.10%-0.21%. These results align with findings in similar studies, like Chen and Zhang (2021) in China and Hanna and Oliva (2015), with a natural experimental

[3] The air pollution data used is the median value of monthly pollution data for city/regency for 2007-2008 and 2014-2015. Labor productivity data comes from IFLS individual data and is accumulated by year of interview using median values for the same period.

approach in Mexico City. Hanna and Oliva (2015) find that a one-unit increase in air pollution (in this term, SO_2 pollutant) makes the work hours drop by 1.3 hours. Furthermore, due to decreasing the labor productivity as cumulative, the firms also acquire the negative impact by dropping the total factor productivity (Li et al., 2020).

VARIABLES	(1) OLS	(2) OLS	(3) OLS	(4) FE	(5) FE	(6) FE	(7) IV	(8) IV	(9) IV
Pollution	0.07	0.05	0.02	0.06	0.01	-0.00	0.00	-0.21	-0.10
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)	(0.05)	(0.04)
Constant	3.43	2.75	5.20	3.42	3.10	-1.47	3.24	2.50	2.16
	(0.01)	(0.05)	(0.57)	(0.00)	(0.13)	(1.36)	(0.06)	(0.07)	(0.88)
R-squared	0.00	0.10	0.11	0.01	0.04	0.05	0.00	0.04	0.10
Individual Control	NO	YES	YES	NO	YES	YES	NO	YES	YES
Regional Control	NO	NO	YES	NO	NO	YES	NO	NO	YES

Robust standard errors in parentheses
$p<0.01$, $p<0.05$, $p<0.1$

Table 2. Baseline Inferential Estimation[4]

Source: RAND Organization (2007 & 2014). GMAO (2023), & BPS (2023), Author's Calculations

There are several essential aspects of the negative impact of air pollution on labor productivity. The time workers are exposed to poor air conditions plays a role in influencing the decline in labor productivity. Estimates from He, Liu, and Salvo (2019) found that the negative impact of air was only felt by the workforce when there was an increase in pollutant levels in the form of PM2.5 by 10 $\mu g/m^3$ for 3-4 weeks, creating a decrease in the production level of labor output by 0.5 %-1%. As the increase continues, the impact of air pollution will remain constant at 0.1% after more than three weeks. Nevertheless, our study uses one-hour satellite data, reflecting the constant pollution in every city/regency in Indonesia. Even with Kim, Manley, and Radoias's (2017) findings using the natural experiment, we see that the air pollution-productivity transmitted in different mediators is related to how long the air pollution exposure is. In the medium effect, it is transmitted via caregiving aspects, but in the long term, the transmitter occurs via labor health status. However, we use the time-averaged one-hourly satellite data with zonal statistics to measure the city/regency level air pollution. We assume the individuals were exposed to constant pollution levels from 2007 to 2015. So, this estimation reflects the long-term exposure effect of air pollution on labor productivity in Indonesia after controlling individual and regional characteristics. Then, we will decompose the negative effect of air pollution on labor productivity.

[4] Cluster Standard error is used in this estimation. Further, we use air temperature as instrumental variable, accompanied with two types of meteorological vector: wind speed and air density.

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	(1)	**(2)**	**(3)**
VARIABLES	Dependent Variable: Hours of worked		
Total Effect	0.00	-0.21	-0.10
	(0.05)	(0.05)	(0.04)
Direct Effect	0.05	-0.03	0.02
	(0.02)	(0.02)	(0.01)
Indirect Effect	-0.05	-0.18	-0.11
	(0.04)	(0.04)	(0.05)
Individual Control	NO	YES	YES
Regional Control	NO	NO	YES

Standard errors in parentheses
p<0.01, p<0.05, p<0.1

Table 3. Mediator Analysis: General Health Status as Mediating Variable[5]

Source: RAND Organization (2007 & 2014). GMAO (2023), & BPS (2023), Author's Calculations

The mediation analysis is then presented in **Table 3**. Using ivmediate, estimates are carried out in Equation 2 to Equation 5. In general, the three model combinations show that air pollution levels increase the likelihood of individuals experiencing illness by 0.10%-0.49% - according to our expectations. Poor individual health levels harm labor productivity. Therefore, health is a transmission of air pollution that influences labor productivity as an indirect effect. In addition, pollution levels can drive changes in labor productivity directly as a direct effect. The total of these two impacts reflects the total effect of air pollution. The estimation results can be seen in **Table 3**.

In the three combinations of model estimates, the value of the total effect is negative in Columns 2

[5] Cluster Standard error is used in this estimation. Further, we use air temperature as instrumental variable, accompanied with two types of meteorological vector: wind speed and air density.

and 3. These results mean that a 1% increase in air pollution decreases productivity by 0.10%-0.21%. Of this total, the indirect effect value through health factors ranges from a large number, namely 0.11%-0.18%. This figure reflects that health is the dominant factor in transmitting the negative impact of air pollution on labor productivity. However, what is interesting is that the direct effect values in Columns 1 and 3 are positive and statistically significant. Thus, it indicates that air pollution can increase labor productivity even though it endangers workers' health. These results are also reflected in Table 1, Columns 1-3 using OLS, which shows a positive relationship between pollution and labor productivity. One potential that makes this happen is the adaptation made by individuals (**see** Hansen-Lewis 2018) in the face of prolonged air pollution so that the impact of pollution can be minimized and not harmful, even possibly increasing labor productivity. However, estimates using IV to mediation analysis clearly show that the model is more robust than OLS to explain the negative impact of air pollution on labor productivity in Indonesia.

IV. Conclusion

Pollution is a detrimental phenomenon that affects various facets of human well-being, encompassing health and productivity. In the context of developing countries like Indonesia, this study employs longitudinal data to scrutinize the intricate relationship between air pollution and labor productivity. The empirical findings of this investigation reveal a significant association wherein air pollution detrimentally impacts the health of the working-age population in Indonesia, consequently leading to a negative influence on their productivity levels.

In an effort to broaden the scope of understanding, this study undertakes a mediation analysis to delve into the mechanisms underlying the relationship between air pollution and labor productivity. The results underscore the pivotal role played by health factors as dominant mediators in transmitting the adverse effects of air pollution to labor productivity. This implies that the nexus between air pollution and labor productivity is intricately woven through the conduit of health-related factors. In quantifying health as a mediator of the pollution-productivity link, this study contributes valuable insights into the nuanced dynamics prevalent in developing countries. In conclusion, the implications of these findings extend beyond the academic realm, prompting actionable recommendations for policy formulation:

1. Given the documented negative impact of air pollution on labor productivity, it is imperative for the government to prioritize this issue. This involves fortifying and rigorously enforcing air quality standards to curtail pollutant levels effectively.
2. Collaborative efforts with various stakeholders can be instrumental in directing investments towards clean and renewable energy sources, thereby reducing reliance on environmentally detrimental fossil fuels.
3. Recognizing the health implications of air pollution, public awareness campaigns can be initiated to educate society about the associated risks, preventing substantial losses stemming from this pervasive phenomenon. These multifaceted recommendations underscore the urgency of comprehensive and collaborative strategies to mitigate the adverse effects of air pollution on both health and productivity in developing countries.

4.1 Recommendation

This research's scope is confined to examining air pollution exclusively. However, future investigations may consider an expanded perspective that encompasses various forms of pollution contributing to the exacerbation of labor productivity issues in Indonesia. In this current analysis, air temperature is the sole instrumental variable for estimation; however, subsequent studies must incorporate additional pertinent instrumental variables to ensure a comprehensive understanding of the dynamics involved. Furthermore, the mediation analysis in this study exclusively relies on self-reported data related to general health status. A more nuanced exploration in future research endeavors could incorporate alternative mediating variables that further elucidate the intricate relationships between pollution and productivity. It is crucial to explore and incorporate diverse mediating transmitters to enhance the robustness and applicability of findings in subsequent investigations.

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Appendix I. Operationalization Variable

Variable Name	Definition	Type	Question from Quetionaire/Formula
Dependent Variable			
Productivity	Individual's working hour past week	Continuous	What was the total number of hours you worked during past week (on your job)? (TK21A)
Outcome of Interest			
Pollution	Total concentration of PM2.5 in air of city/regency level (in natural logarithm form)	Continuous	Duss Mass Concentration – PM2.5 from GMAO
Individual Controls			
Health Insurance	=1 if individual is policy holder/primary beneficiary of health benefits, health insurance and =0 if otherwise	Binary	Are you the policy holder/primary beneficiary of health benefits, health insurance, such as ASKES, ASTEK/JAMSOSTEK, employer provided medical reimbursement, employer provided clinic, private health insurance, savings-related insurance, health card or ASKESKIN?
Sector	Sector of individual's primary job	Categorical	Code for sectors of primary job
Smoking	Individual's status of smoking behavior	Categorical	Do you still have the habit or have you totally quit? (KM04)
Education	Individual's highest school ever attended	Categorical	What is the highest education level attended? (DL06)
Age	Current age of individual	Continuous	Age now (AR09)
Square of Age	Square age of individual	Continuous	$agesq = age^2$
Marital Status	Individual's marital status	Categorical	Marital status (AR13)
Urban	= 1 if individual lives in urban area, =0 if otherwise	Binary	Area: 1. Urban 2. Rural (SC05)
Gender	= 1 if individual's gender is male, =0 if otherwise	Binary	Sex (AR07)
Household Controls			
House Ownership	Occupied house's status of the household	Categorical	What is the status of this house? (KR03)
Vehicle Ownership	=1 if individu/household had vehicle, =0 if otherwise	Binary	Do you or does any other member of the household own vehicle? (HR01 for HRTYPE E)
Regional Control			
Population Density	Total population density per km^2 at province level (in natural logarithm form)	Continuous	Population Density per Province (BPS)
Nominal GDRP	Nominal Gross Domestic Regional Product of province	Continuous	Nominal Gross Domestic Regional Product of province (BPS)
Inflation	Inflation Level (in natural logarithm form)	Continuous	GDP Deflator (BPS)
Human Development Index	Human Development Index (HDI) at province level (in natural logarithm form)		Human Development Index (BPS)
Instrument Variable			
Air Temperature	Surface air temperature at city/regency level (in natural logarithm form)	Continuous	Surface Flux Diagnostics (GMAO)
Meteorological Vector			
Wind Speed	Surface wind speed at city/regency level (in natural logarithm form)	Continuous	Surface Flux Diagnostics (GMAO)
Air Density	Air density at surface at city/regency level (in natural logarith form)	Continuous	Surface Flux Diagnostics (GMAO)
Mediator Variable			
Health	=1 if individual health's condition is unhealth/somewhat unhealth, =0 if otherwise	Binary	In general, how is your health? (KK01 for >15 years old & MAA for <15 years old)

Appendix II. Full Baseline Estimation

VARIABLES	(1) OLS	(2) OLS	(3) OLS	(4) FE	(5) FE	(6) FE	(7) IV	(8) IV	(9) IV
Air Pollution	0.07	0.05	0.02	0.06	0.01	-0.00	0.00	-0.21	-0.10
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)	(0.05)	(0.04)
Primary Education		-0.04	-0.02		0.06	0.05		-0.04	-0.02
		(0.02)	(0.02)		(0.05)	(0.05)		(0.02)	(0.02)
Secondary Education (SMP/Sederajat)		-0.05	-0.02		0.11	0.10		-0.06	-0.02
		(0.03)	(0.03)		(0.07)	(0.07)		(0.03)	(0.03)
Secondary Education (SMA/Sederajat)		-0.08	-0.04		0.12	0.12		-0.07	-0.03
		(0.02)	(0.02)		(0.08)	(0.08)		(0.03)	(0.03)
Tertiary Education		-0.21	-0.17		0.21	0.21		-0.21	-0.16
		(0.03)	(0.03)		(0.09)	(0.09)		(0.03)	(0.03)
Others Education		-0.13	-0.11		0.22	0.21		-0.11	-0.10
		(0.08)	(0.08)		(0.12)	(0.12)		(0.08)	(0.07)
Don’t Know/Missing		0.48	0.50		0.69	0.68		0.35	0.48
		(0.32)	(0.32)		(0.30)	(0.31)		(0.40)	(0.35)
Self-Employed with Unpaid Worker		0.19	0.20		0.07	0.07		0.20	0.20
		(0.02)	(0.02)		(0.03)	(0.03)		(0.02)	(0.02)
Self-Employed with Permanent Worker		0.18	0.18		0.03	0.03		0.17	0.18
		(0.04)	(0.04)		(0.06)	(0.06)		(0.04)	(0.04)
Government Worker		0.22	0.19		0.19	0.18		0.26	0.19
		(0.02)	(0.02)		(0.05)	(0.05)		(0.02)	(0.02)
Private Worker		0.27	0.28		0.24	0.23		0.28	0.28
		(0.02)	(0.02)		(0.03)	(0.03)		(0.02)	(0.02)
Unpaid Family Worker		-0.04	-0.05		-0.10	-0.10		-0.02	-0.05
		(0.02)	(0.02)		(0.04)	(0.04)		(0.02)	(0.02)
Casual Worker in Agriculture		0.13	0.12		0.16	0.15		0.12	0.12
		(0.03)	(0.03)		(0.05)	(0.05)		(0.03)	(0.03)
Casual Worker not in Agriculture		0.00	0.01		0.05	0.05		-0.00	0.01
		(0.02)	(0.02)		(0.04)	(0.04)		(0.02)	(0.02)
Others		0.29	0.31		1.09	1.10		0.32	0.30
		(0.23)	(0.24)		(0.05)	(0.10)		(0.04)	(0.20)
Secondary Sector		0.29	0.28		0.20	0.21		0.29	0.29
		(0.02)	(0.02)		(0.03)	(0.03)		(0.02)	(0.02)
Tertiary Sector		0.25	0.25		0.17	0.17		0.25	0.25
		(0.01)	(0.01)		(0.03)	(0.03)		(0.01)	(0.01)
Others		-0.03	0.01		-0.03	-0.02		-0.14	0.01
		(0.06)	(0.06)		(0.09)	(0.09)		(0.07)	(0.06)
Have Health Insurance		-0.02	0.00		-0.01	-0.01		-0.06	0.00
		(0.01)	(0.01)		(0.02)	(0.02)		(0.01)	(0.01)
Occupying		-0.09	-0.10		-0.01	-0.01		-0.11	-0.11

		(0.02)	(0.02)		(0.04)	(0.04)		(0.02)	(0.02)
Self-Owned		-0.09	-0.11		-0.03	-0.04		-0.14	-0.12
		(0.02)	(0.02)		(0.04)	(0.04)		(0.02)	(0.02)
Others		0.00	-0.02		0.18	0.16		-0.06	-0.04
		(0.11)	(0.10)		(0.17)	(0.17)		(0.11)	(0.11)
Don’t Know/Missing		-0.13	-0.09		-0.06	-0.05		-0.21	-0.08
		(0.19)	(0.19)		(0.16)	(0.16)		(0.20)	(0.19)
Not Anymore		-0.05	-0.03		-0.04	-0.03		-0.06	-0.02
		(0.02)	(0.02)		(0.04)	(0.04)		(0.02)	(0.02)
Still Smoke		-0.00	0.01		0.00	0.01		0.01	0.01
		(0.01)	(0.01)		(0.03)	(0.03)		(0.01)	(0.01)
Have Vehicle		-0.03	-0.01		-0.02	-0.02		-0.06	-0.01
		(0.01)	(0.01)		(0.02)	(0.02)		(0.01)	(0.01)
Age		0.02	0.03		0.02	0.06		0.02	0.03
		(0.00)	(0.00)		(0.01)	(0.01)		(0.00)	(0.00)
Square of Age		-0.00	-0.00		-0.00	-0.00		-0.00	-0.00
		(0.00)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)
Married/Cohabitate		0.04	0.02		-0.01	-0.01		0.07	0.02
		(0.02)	(0.02)		(0.04)	(0.04)		(0.02)	(0.02)
Divorce/Widow		-0.01	-0.02		-0.08	-0.08		0.01	-0.02
		(0.03)	(0.03)		(0.06)	(0.06)		(0.03)	(0.03)
Urban		0.03	0.04		-0.01	0.00		0.04	0.05
		(0.01)	(0.01)		(0.03)	(0.03)		(0.01)	(0.01)
Male		0.21	0.20					0.22	0.20
		(0.01)	(0.01)					(0.01)	(0.01)
Nominal Gross Domestic Regional Product			-0.01			-0.03			-0.00
			(0.01)			(0.05)			(0.01)
Inflation			0.28			0.28			0.45
			(0.02)			(0.08)			(0.07)
Population Density			0.01			-0.58			-0.02
			(0.01)			(0.09)			(0.01)
Human Development Index			-0.92			1.36			-0.46
			(0.14)			(0.36)			(0.17)
Wind Speed							-0.12	-0.11	-0.09
							(0.02)	(0.02)	(0.02)
Air Density							1.77	2.36	1.78
							(0.27)	(0.27)	(0.28)
Constant	3.43	2.75	5.20	3.42	3.10	-1.47	3.24	2.50	2.16
	(0.01)	(0.05)	(0.57)	(0.00)	(0.13)	(1.36)	(0.06)	(0.07)	(0.88)
Observations	28,111	28,032	28,032	28,111	28,032	28,032	28,111	28,032	28,032
R-squared	0.00	0.10	0.11	0.01	0.04	0.05	0.00	0.04	0.10

Robust standard errors in parentheses

p<0.01, p<0.05, p<0.1